Considerations on In-Band and Out-of-Band Signalling Constraints in OBS Networks

Antonio Pantaleo, Massimo Tornatore and Achille Pattavina
Carla Raffaelli and Franco Callegati

Polytechnic of Milan, Department of Electronics and Information, Milan, Italy
*University of Bologna, Department of Electronics Information and Systems, Bologna, Italy

ABSTRACT
Most of previous works on Optical Burst Switching (OBS) assume in their analysis that signalling does not affect network performance. In this paper we analyze under which conditions the effect of signalling is actually negligible, taking into account the effect of signalling in the evaluation of burst discard probability. We use two analytical models for two different signalling techniques in an OBS network: out-of-band and in-band technique. We evaluate the impact of these two signalling strategies in term of the probability of burst discard. We also discuss a new method to assign the correct amount of resources to the control plane. To verify the accuracy of the proposed models, analytical results are compared with results based on discrete-event simulations and are found to be in very satisfactory agreement.

Keywords: optical burst switching, in-band signalling, out-of-band signalling, signalling delay.

1. INTRODUCTION
Optical Burst Switching (OBS) [1] is a new hybrid paradigm for optical transport networks which has been proposed as compromise between the static nature of Optical Circuit Switching (OCS) and the high future dynamicity of Optical Packet Switching (OPS).

The OBS transport architecture is based on a bufferless WDM network, where data bursts consisting of multiple packets are created at border or ingress nodes and switched by intermediate or core nodes along the network all-optically. This is possible thanks to a control message or header which is transmitted ahead of the burst and whose goal is to configure the switches along the path before the arrival of the corresponding data burst.

Current literature has investigated numerous aspects of this technique (e.g., assembling, scheduling, contention resolution, reservation) and their impact on burst loss [2]. A common consideration was that control plane (signalling) impact on general performance was reasonably negligible. In this paper we try to determine under which conditions the control plane is really negligible: we consider out-of-band signalling mechanism, in which headers have their own dedicated channels, and in-band signalling mechanism, in which header messages share the same resource of data bursts. All the following analysis is carried under the assumption of system parameters coming from a “near future” scenario as discussed in [2].

The rest of the paper is organized as follow. In section 2 we present simple, yet effective analytical models to evaluate burst discard probability in an optical core node in the case of out-of-band signalling: based on this analysis, obtained results are discussed. In section 3 an iterative approach for control resources dimensioning is proposed. In Section 4 we consider in-band signalling, providing an approximated analytical model to measure the blocking probability and then we discuss a control queue dimensioning methodology to soothe the effects of control plane on blocking probability.

2. OUT-OF-BAND SIGNALLING
In this section we evaluate the impact of Out-of-Band (OuB) signalling on burst loss in an optical core node. The functional and physical division between the two planes allows us to treat control and data plane as distinct subsystems, exploiting two separate but interdependent queue models. Since there is a fixed division between the number of data and signalling channels (wavelengths), in the following we refer to them respectively with n and k. The number of channels available on each link is W, so W = k + n.

2.1 Modelling Data Plane at Core Node
Some preliminary considerations on the characteristics of traffic in OBS networks are needed to introduce our model. In fact, as far as the burst interarrival statistic is concerned, although the IP traffic nature is self similar, the burst traffic becomes much less bursty in virtue of the packet aggregation process at the ingress node [3]. So, we assumed that input burst short range statistic is Poisson. On the other side, burst length statistic is heavily dependent on the assembly procedure [3]–[4] and we have decided to model each data subsystem as an M/G/n queue model. The use of the General service distribution assumption allows us to maintain our analytical...
approach simple and as much general as possible. Under this hypothesis, we model the burst blocking probability $P_b$ with Erlang-B formula.

2.2 Modelling Control Plane at Core Node

Since a single control packet is sent per burst, we can assume that headers interarrival distribution follows the same distribution of data bursts interarrival. As a consequence, we can model each control subsystem as an $M/M/k/(k+q_c)$, where $q_c$ is the length of the headers queue at each node, needed to store the control information.

Under this assumption, the header lost probability $P_h$ can be calculated as the buffer overflow probability, i.e. the probability that there are almost $k + q_c$ message in the control system

$$P_h = P_{k+q_c} = \left( \frac{\rho_h}{k!} \right)^k \sum_{i=0}^{k} \frac{\rho_h^i}{i!} + \sum_{i=1}^{\infty} \left( \frac{\rho_h}{i} \right)^i \left( \frac{\rho_h}{k} \right)^i \left( 1 + \frac{\rho_h}{k} \right)^{-1}$$

With $P_h$ and $n_q$ we are finally able to obtain the mean queuing time $T_q$ from Little’s Formula.

3. PERFORMANCE ANALYSIS OF AN OUT-OF-BAND SIGNALLING SYSTEM

In this section we evaluate the effect of the control plane constraints on OBS network assuming an out-of-band signalling scheme. To validate our models, we developed a discrete event simulation program based on OMNet++: we use the well known JET signalling protocol and adopted realistic functional parameters (i.e. switching and processing times) [5]-[6]. As scheduling references we chose First Fit Unused Channel (FF) and Last Available Unused Channel with Void-Filling (VF) mechanism for their simplicity and occurrence in literature. We assumed to have a fixed number of wavelengths $W = 8$, each with a capacity of 10 Gbit/s; so, the mean transmission time for control packet and burst are 1µs and 100µs, respectively. Note that, in an OBS network, to correctly evaluate the actual waiting time for a header we must also consider the processing time $T_p$ (in our simulations $T_p = 20µs$). We compared analytical with simulative results to verify the trustability of our models obtaining a very satisfactory agreement (in the following, these comparisons are usually not reported for sake of conciseness). The overall blocking probability at $i$-th node is now given by:

$$P_b = P_b + (1 - P_h) P_h$$

We divide our analysis in two scenarios: first, we evaluate systems without control queue to observe the pure impact of signaling; then, we consider that headers can be stored in buffers at the intermediate nodes: in this case, we have not only to evaluate the blocking probability of the headers, but we have also to take into account that the signalling delay induced by queuing time of control messages is a possible cause of burst loss.

3.1 Oub Pure Loss Control Subsystem

In the first scenario without control queue, based on the previous parameters and for an offered data load of, e.g., 0.525 Erl, Erlang-B and equation (1) return $P_h = 0.0733$ and $P_b = 0.0403$, respectively. Apparently, in this case the probability of header loss is not negligible and could affect the overall blocking probability in equation (3).

A possible solution to decrease the value of $P_h$ consists in increasing the number of wavelengths assigned to signalling. Considering that the number of wavelengths is fixed, we can explore different data-control wavelengths combinations and compare the overall blocking probability in the various cases. In Fig. 1 we report the percentage of the burst loss due to limited transmission capacity and the percentage of bursts lost because the corresponding headers have been dropped (in other words, due to limited transmission capacity) applying VF. We observe that for low traffic intensity, header loss is the leading component of overall burst discard probability while for high traffic intensity, burst loss is much more significant. It is worth pointing out that FF returns the same results as VF, since we have not fiber delay lines and offset time is the same for all burst.

3.2 Oub Queuing Control Systems

In this scenario, we consider a core node equipped by a control queue for the headers to prevent header loss. Note that, when headers are queued, their mean waiting time $T_w$ has to be kept under control, since we must guarantee that the offset-time is not consumed by an excessive delay induced by queuing times. These two conditions can be summarized as follow:

$$\begin{cases} P_h < e & P_h \\ T_w = T_q + n_q T_p < T_{ul} \end{cases}\quad (4)$$
where $\epsilon = 10^{-2}$ expresses the desired difference between burst loss and header loss probability and $T_{\text{tol}}$ is the maximal delay tolerable in a node. Since processing, switching and transmission times are in order of tens of microseconds, a reasonable value for $T_{\text{tol}}$ should be relatively shorter. In the following, we use a $T_{\text{tol}}$ of 1 $\mu$s.

### 3.3 Optimization Procedures

Based on previous considerations, we propose an iterative method to choose the best data-control wavelengths combination in the network given a target on $P_B$ and $\epsilon$ and satisfying the constraints in equation (4). We assume that the overall number of wavelengths in the system $W$ is fixed. To start our procedure, we assign a single channel for signalling and all the remaining channels to bursts. Given the target $P_B$, we can retrieve an initial acceptable load $\rho$ by inverting the Erlang-B formula; then, according to the desired $\epsilon$, we can find the queue depth so that $P_B$ is actually negligible. This solution is acceptable only if the delay constraint is satisfied: if this constraint is violated, then we add a control wavelength by removing a data wavelength. Since the number of data channel has decreased, a new maximal acceptable load has to be recalculated. This operation is iterated until the delay constraint is satisfied (see diagram in Fig. 2). The result of this procedure is the data:control channels combination supporting the maximal acceptable load and satisfying the constraints.

![Figure 2. Flow-chart of the proposed dimensioning procedure.](image)

E.g., let us consider a 128 channels WDM system with a target $P_B < 10^{-6}$ and $\epsilon = 10^{-2}$. A first possible combination is 127:1. With $n = 127$ and the required $P_B$, an 82 Erl load is acceptable; a control queue $q_c = 84$ is needed to make $P_B$ negligible, but the only mean queuing time $T_q$ is equal to 5 $\mu$s and does not respect equation (4). So, we iterate the algorithm: considering a 126:2 system, the new acceptable load is 81 Erl: the queue length needed is $q_c = 19$ but the delay constraint is not respected yet. Only considering a 125:3 system, both the constraints are finally satisfied with an acceptable load of 80 Erl and $q_c = 12$.

### 4. In-Band Signalling

In this section we evaluate the impact of In-Band (IB) signalling on burst loss: in this case, headers travel along the same wavelength channels available for data bursts. So, the whole system can not be modeled as two separated (control and data) subsystems as in the previous case, but a unique model has to be used.

#### 4.1 IB Pure Loss Control Subsystem

First, we consider the pure loss model control subsystem case. The system can be represented by a two-dimensional non-homogeneous Markov Chain. An exact model to express $P_B$ would require the full knowledge of the actual conjunct probabilities. Since this distribution can not be a-priori retrieved, we propose to give a weight to states probabilities using a basic triangular function and assuming the independence between headers and bursts arrivals: this weight assignment allows us to capture the larger relevance of the states where the
number of headers and bursts is similar. Obtained results are confirmed by the simulative curves, especially for medium-low loads. For higher loads the proposed model returns an upper bound to the actual performance.

4.2 IB Queuing Control Subsystem
The introduction of header queuing at the control plane in the IB case allows to drastically reduce header losses: all the channels are shared by bursts and headers and, whenever a header-burst contention arise, the header can be queued. Nonetheless, also in this case, we still have to check the conditions in equation (4): the length of the control queue (to guarantee a negligible $P_h$), and the waiting time $T_w$ (to verify if the it is less than $T_{tol}$). In the following, we propose a simple method to estimate the value of these two key parameters.

The value of $q_c$ is set to the mean number of headers that arrive in a mean burst duration: note that the worst case for a header is when all channels have been already occupied by bursts (if headers, then the waiting time would be much shorter). In the negative exponential case, the residual lifetimes of all services are still exponential. So, to make the buffer overflow almost negligible, it will be enough to assign a buffer length able to accommodate the headers that, on average, may arrive during an average burst duration: this value is given by $\frac{1}{\lambda \mu}$. The performance of this approximated queue-length choice has been verified also by simulation.

To approximately evaluate $T_w$ we have used a similar approach. Since headers have shorter duration than burst, the probability that a header contends a channel to another header is almost negligible. So, we can assume that a header is queued mainly when $W$ bursts are in the system at the same time and, in that case, a header stays in the queue as far as one of the $W$ bursts in the system is completely transmitted. This can be formally stated as the product of the $P_h$ with the mean of the distribution of the minimum among $W$ casual variables representing the residual lifetimes of the $i$-th (under service) burst. Because of the memoryless property of negative exponential, the new distribution is still exponential with parameter $W \mu_h$.

In conclusion, in the IB scenario $T_w$ can not be modulated but it is fixed according to the network load and capacity. So due to queue introduction, we have now to take into consideration the variable queuing and processing delay. Note that, with a FIFO-like queue, a header must wait its turn to be served but also the processing time of previous headers. These new terms must be included in the offset time definition, according to the extended formula

$$T_{offset} = h \left( n_q T_s + T_p \right) + T_r$$

where $h$ is the number of hops, $n_q$ is the mean number of headers in queue, $T_s$ and $T_p$ stand for switching and processing time respectively. Finally, it is worth noting that while $T_s$ and $T_p$ will probably reduce in the next years thanks to technology evolution [2], $n_q$ reduction could be obtained only by means of an effective network design.

5. CONCLUSIONS
In this paper, we have investigated the effects on OBS network performance of out-of-band and in-band signalling under two different scheduling algorithms (FF and VF). For each architecture, we have shown how the adoption of a queue at the control plane can drastically decrease the portion of bursts discarded due lost headers and we have shown how to quantify the amount of control resources necessary to avoid burst loss due to an excessive header queuing. While in the out-of-band case, the header queuing time can be adjusted by adding more resources to signalling, in the in-band scenario the mean header queuing time is strictly dependent on network load and resources and becomes necessary to include it in the network signalling design.

REFERENCES